ENGINEERING DEVELOPMENT OF COAL-FIRED HIGH-PERFORMANCE POWER SYSTEMS

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ABSTRACT

A High Performance Power System (HIPPS) is being developed. This system is a coal-fired, combined cycle plant with indirect heating of gas turbine air. Foster Wheeler Development Corporation and a team consisting of Foster Wheeler Energy Corporation, Bechtel Corporation, University of Tennessee Space Institute and Westinghouse Electric Corporation are developing this system. In Phase 1 of the project, a conceptual design of a commercial plant was developed. Technical and economic analyses indicated that the plant would meet the goals of the project which include a 47 percent efficiency (HHV) and a 10 percent lower cost of electricity than an equivalent size PC plant.

The concept uses a pyrolysis process to convert coal into fuel gas and char. The char is fired in a High Temperature Advanced Furnace (HITAF). The HITAF is a pulverized fuel-fired boiler/air heater where steam is generated and gas turbine air is indirectly heated. The fuel gas generated in the pyrolyzer is then used to heat the gas turbine air further before it enters the gas turbine.

The project is currently in Phase 2 which includes engineering analysis, laboratory testing and pilot plant testing. Research and development is being done on the HIPPS systems that are not commercial or being developed on other projects. Pilot plant testing of the pyrolyzer subsystem and the char combustion subsystem are being done separately, and after each experimental program has been completed, a larger scale pyrolyzer will be tested at the Power Systems Development Facility (PSDF) in Wilsonville, AL. The facility is equipped with a gas turbine and a topping combustor, and as such, will provide an opportunity to evaluate integrated pyrolyzer and turbine operation.

This report addresses the areas of technical progress for this quarter. In order to prepare the CETF for the HIPPS char combustion test program, the detailed design of a new indirect char feeding system to be used for the wall-fired char combustion tests was completed during this quarter. Testing of the wall-fired burner is essential for the development of the HIPPS repowering technology. In order for the HIPPS repowering technology to have broad range appeal, its application must not be limited exclusively to the arch-fired arrangement.

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EXECUTIVE SUMMARY

The High Performance Power System is a coal-fired, combined cycle power generating system that will have an efficiency of greater than 47 percent (HHV) with NOx and SOx less than 0.025 Kg/GJ (0.06 lb/MMBtu). This performance is achieved by combining a coal pyrolysis process with a High Temperature Advanced Furnace (HITAF). The pyrolysis process consists of a pressurized fluidized bed reactor which is operated at about 926°C (1700°F) at substoichiometric conditions. This process converts the coal into a low-Btu fuel gas and char. These products are then separated.

The char is fired in the HITAF where heat is transferred to the gas turbine compressed air and to the steam cycle. The HITAF is fired at atmospheric pressure with pulverized fuel burners. The combustion air is from the gas turbine exhaust stream. The fuel gas from the pyrolysis process is fired in a Multi-Annular Swirl Burner (MASB) where it further heats the gas turbine air leaving the HITAF. This type of system results in very high efficiency with coal as the only fuel.

We are currently in Phase 2 of the project. In Phase 1, a conceptual plant design was developed and analyzed both technically and economically. The design was found to meet the project goals. The purpose of the Phase 2 work is to develop the information needed to design a prototype/commercial plant. Phase 3 of the overall HIPPS contract has been deleted. In addition to engineering analysis and laboratory testing, the subsystems that are not commercial or being developed on other projects will be tested at pilot plant scale. The FWDC Second-Generation PFB pilot plant in Livingston, NJ, has been modified to test the pyrolyzer subsystem. The FWDC Combustion and Environmental Test Facility (CETF) in Dansville, NY, has been modified to test the char combustion system. Integrated operation of a larger scale pyrolyzer and a commercial gas turbine are planned for the PSDF in Wilsonville, AL.

The detailed design of the major process equipment to be installed at the pilot plant in Livingston, New Jersey is underway. The existing bubbling bed plant is to be modified to a circulating mode of operation. Further work has been completed to better understand how the HIPPS concept can be applied to advanced cycle arrangements.

INTRODUCTION

In Phase 1 of the project, a conceptual design of a coal-fired high performance power system was developed, and small scale R&D was done in critical areas of the design. The current Phase of the project includes development through the pilot plant stage.

Foster Wheeler Development Corporation (FWDC) is leading a team of companies in this effort. These companies are:

- Foster Wheeler Energy Corporation (FWEC)
- Bechtel Corporation
- Westinghouse Electric Corporation

The power generating system being developed in this project will be an improvement over current coal-fired systems. Goals have been identified that relate to the efficiency, emissions, costs and general operation of the system. These goals are:

- Total station efficiency of at least 47 percent on a higher heating value basis.
- Emissions:

  NOx < 0.06 lb/MMBtu
  SOx < 0.06 lb/MMBtu
  Particulates < 0.003 lb/MMBtu

- All solid wastes must be benign with regard to disposal.
- Over 95 percent of the total heat input is ultimately from coal, with initial systems capable of using coal for at least 65 percent of the heat input.

The base case arrangement of the HIPPS cycle is shown in Figure 1. It is a combined cycle plant. This arrangement is referred to as the All Coal HIPPS because it does not require any other fuels for normal operation. A fluidized bed, air blown pyrolyzer converts coal into fuel gas and char. The char is fired in a high temperature advanced furnace (HITAF) which heats both air for a gas turbine and steam for a steam turbine. The air is heated up to 760^{o}C (1400^{o}F) in the HITAF, and the tube banks for heating the air are constructed of alloy tubes. The fuel gas from the pyrolyzer goes to a topping combustor where it is used to raise the air entering the gas turbine to 1288^{o}C (2350^{o}F). In addition to the HITAF, steam duty is achieved with a heat recovery steam generator (HRSG) in the gas turbine exhaust stream and economizers in the HITAF flue gas exhaust stream.

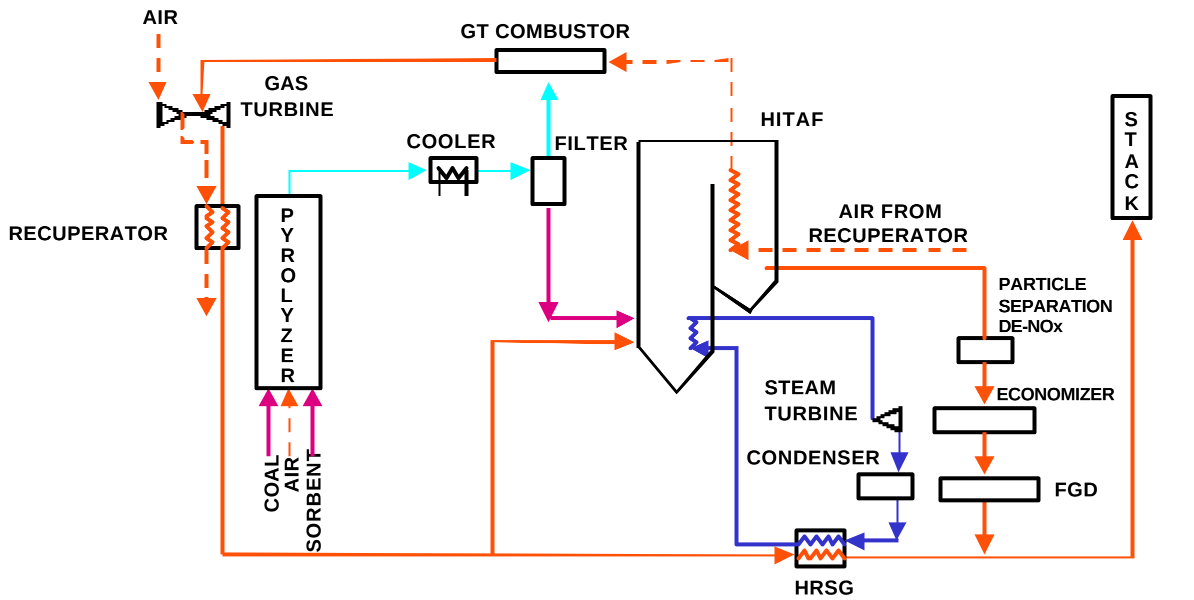

Figure 1 All Coal Fired HIPPS

An alternative HIPPS cycle is shown in Figure 2. This arrangement uses a ceramic air heater to heat the air to temperatures above what can be achieved with alloy tubes. This arrangement is referred to as the 35 percent natural gas HIPPS, and a schematic is shown in Figure 2. A pyrolyzer is used as in the base case HIPPS, but the fuel gas generated is fired upstream of the ceramic air heater instead of in the topping combustor. Gas turbine air is heated to 760°C (1400°F) in alloy tubes the same as in the All Coal HIPPS. This air then goes to the ceramic air heater where it is heated further before going to the topping combustor. The temperature of the air leaving the ceramic air heater will depend on technological developments in that component. An air exit temperature of 982°C (1800° F) will result in 35 percent of the heat input from natural gas.

A simplified version of the HIPPS arrangement can be applied to existing boilers. Figure 3 outlines the potential application of the HIPPS technology for repowering existing pulverized coal fired plants. In the repowering application, the gas turbine exhaust stream provides the oxidant for co-fired combustion of char and coal. The existing boiler and steam turbine infrastructure remain intact. The pyrolyzer, ceramic barrier filter, gas turbine, and gas turbine combustor are integrated with the existing boiler to improve overall plant efficiency and increase generating capacity.

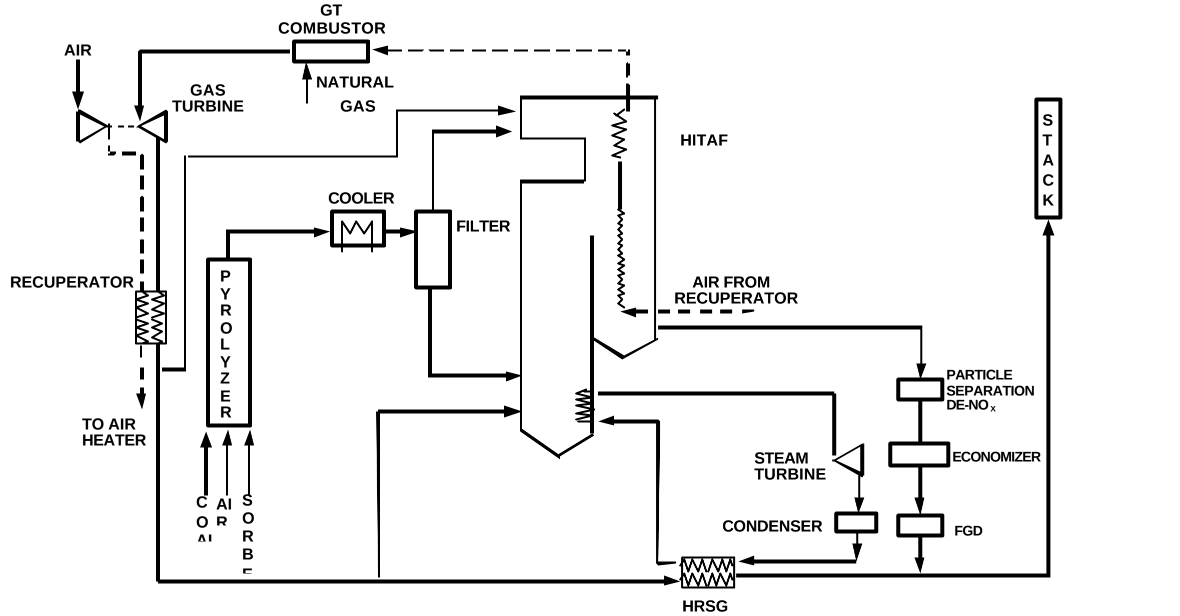

Figure 2 35-Percent Natural Gas

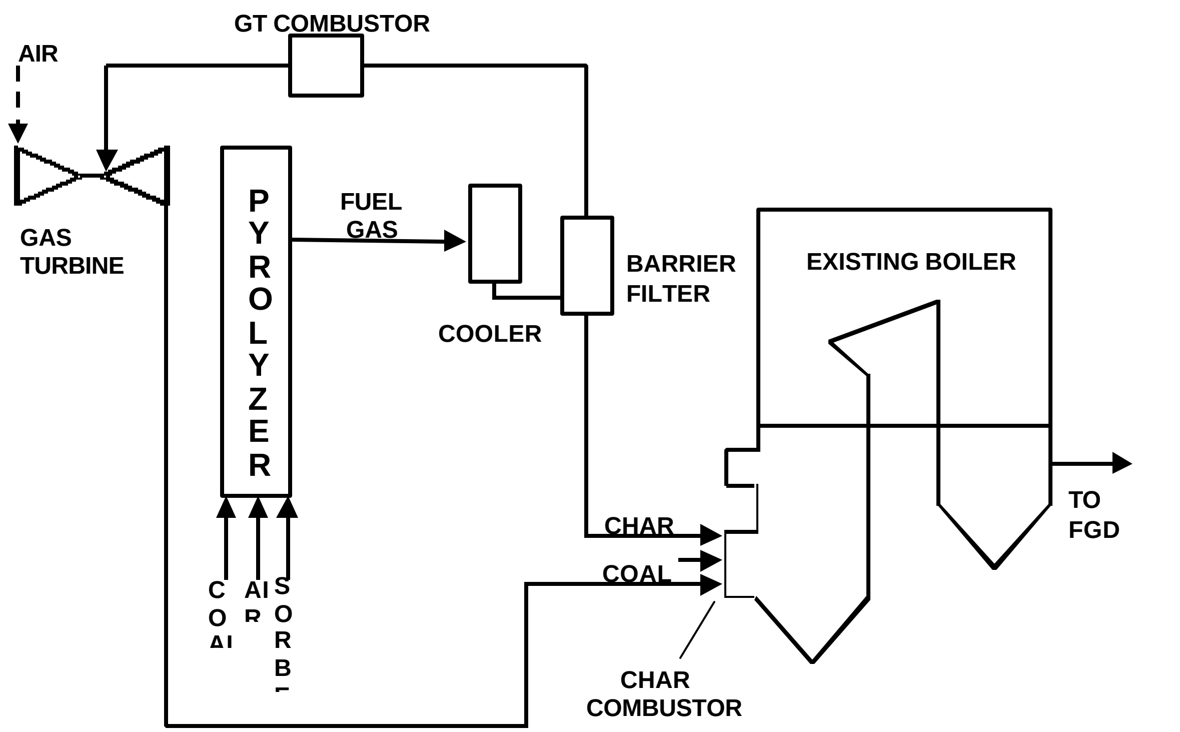

Figure 3 Simplified HIPPS Repowering Process Flow Diagram

TECHNICAL PROGRESS

Task 1 - Project Planning and Management

Work is progressing according to the process plan.

Task 2 – Engineering Research and Development

No engineering R&D work was performed during this quarter.

Task 3 - Subsystem Test Unit Design

Subtask – 3.2 Char Combustion System Test Design

In our previous burner tests at our Combustion and Environmental Test Facility (CETF) in Dansville, New York, an indirect feed system was employed to deliver char to the burner in the arch-fired configuration. This system did not perform as originally specified by the vendor, and the fuel flow to the burner was unstable. In order to meet the test objectives for the new wall-fired burner, the fuel flow must be steady and controllable. The modifications to the existing indirect feed system is needed to improve both system performance and accuracy. Testing of the wall-fired burner is essential for the development of the HIPPS repowering technology. In order for the HIPPS repowering technology to have broad range appeal, its application must not be limited exclusively to the arch-fired arrangement.

A process schematic of the CETF for the new wall-fired configuration is presented in Figure 4. The new design of the char silo and indirect feed system is shown in Figure 5. The new feed system is a loss-in-weight and pneumatic conveying feed system designed to meet the following specification:

Material Properties:	
Material:	Pulverized Char
Density:	20-50 lb/cu ft
Particle Size:	70%-95% < 75 microns
Surface Moisture:	1% Max.
Design Parameters:	
Max. Capacity:	9000 lb/hr
Min. Capacity:	900 lb/hr
Accuracy:	+/- 1% (based on weight)
Pneumatic Conv. Air Flow, Max:	18,000 lb/hr
Pneumatic Conv. Air Flow, Min:	675 lb/hr
Operation:	

Indirect pulverized char feed system will be supplementing the pulverized char feed from the ball mill. Thus, the silo will be filled either from the ball mill with the indirect pulverized char system off line, or from a truck as a batch fill.

The major modification to the existing indirect feed system includes the following:

a) Materials to modify existing pulverized char silo to accommodate four (4) point load cell system.
b) Existing silo load cell assembly consisting of four (4) load cells, mounting hardware.
c) 70° silo transition from existing 6'ϕ silo outlet to manually actuated silo isolation gate. Silo transition includes a nitrogen aeration system.
d) Loss-in-weight system consisting of:
    - manual silo isolation valve
    - pneumatically actuated refill valve
    - inlet isolation joint
    - loss-in-weight hopper with load cell assembly and vent connection
    - hopper nitrogen aeration system
    - loss-in-weight hopper agitator
    - rotary feeder
    - inclined screw feeder with outlet transition and isolation joint
    - instrumentation and controls
e) Pneumatic conveying feed system consisting of:
    - vent wye
    - rotary feeder
    - pneumatic conveying line pick-up tee.

Figure 6 shows the instrumentation and control systems for the new indirect feed system.

Task 4 - Subsystem Test Unit Construction

Vendors to supply this new indirect feed system modification work were selected and awarded during this report period. Some modifications and demolition works are being made to the existing feed system in preparation for the new system construction. The overall construction and testing schedule for the wall-fired char combustion test is shown in Figure 7.

Task 5 - Subsystem Test Unit Testing

No experimental testing was performed during this quarter

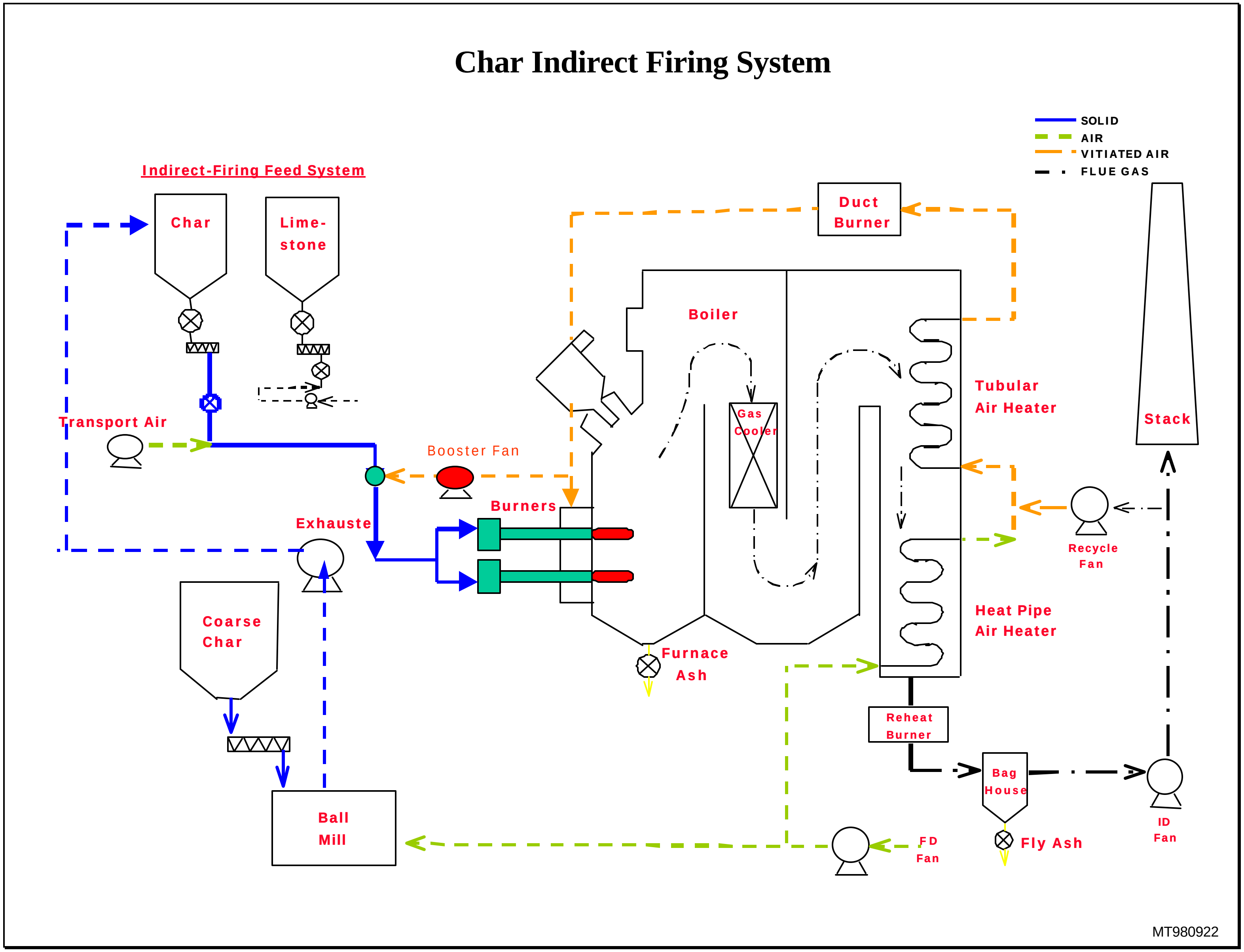

Figure 4 CETF Process Schematic

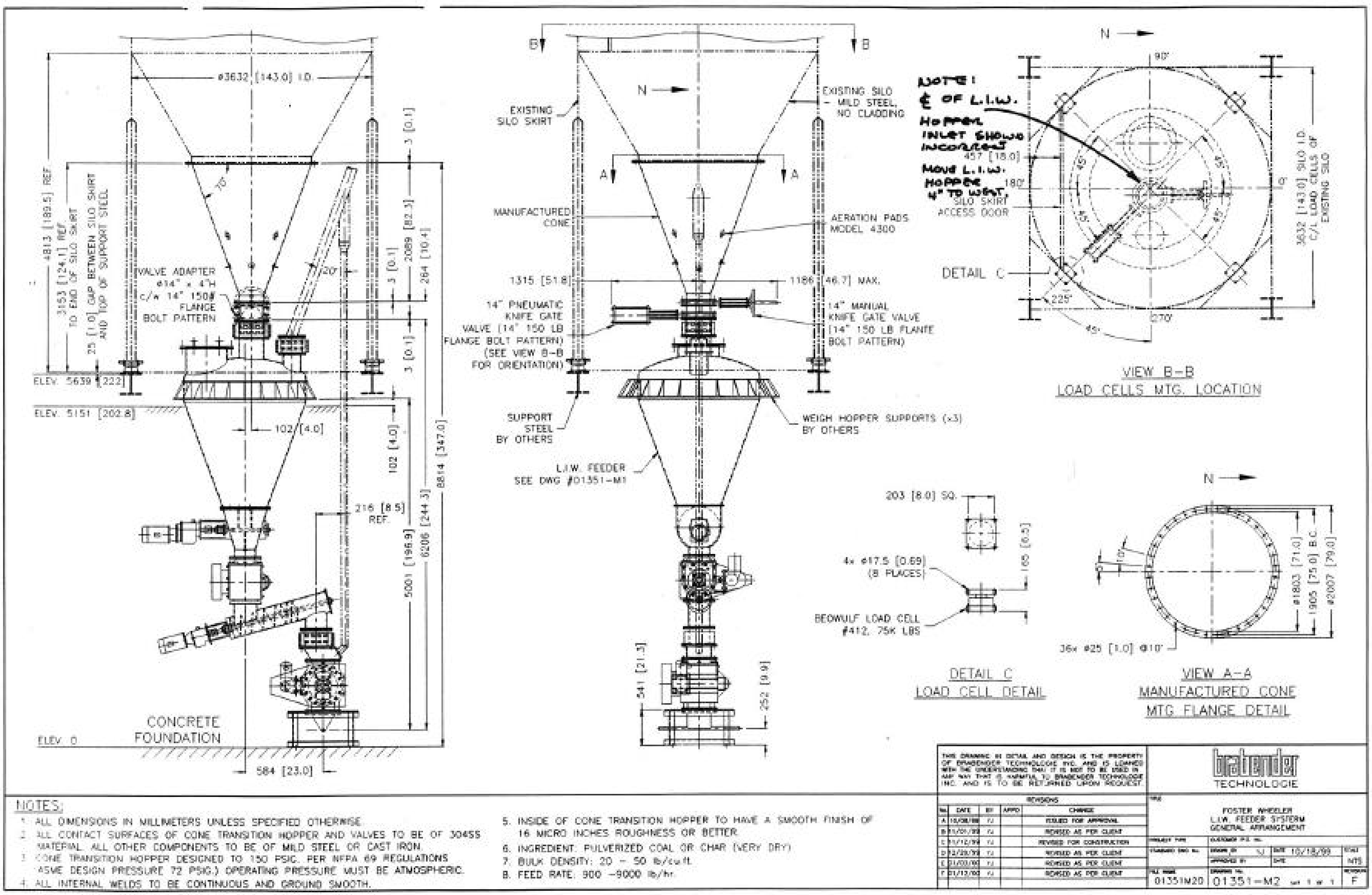

Figure 5 New Loss-in-Weight and Pneumatic Conveying Feed System

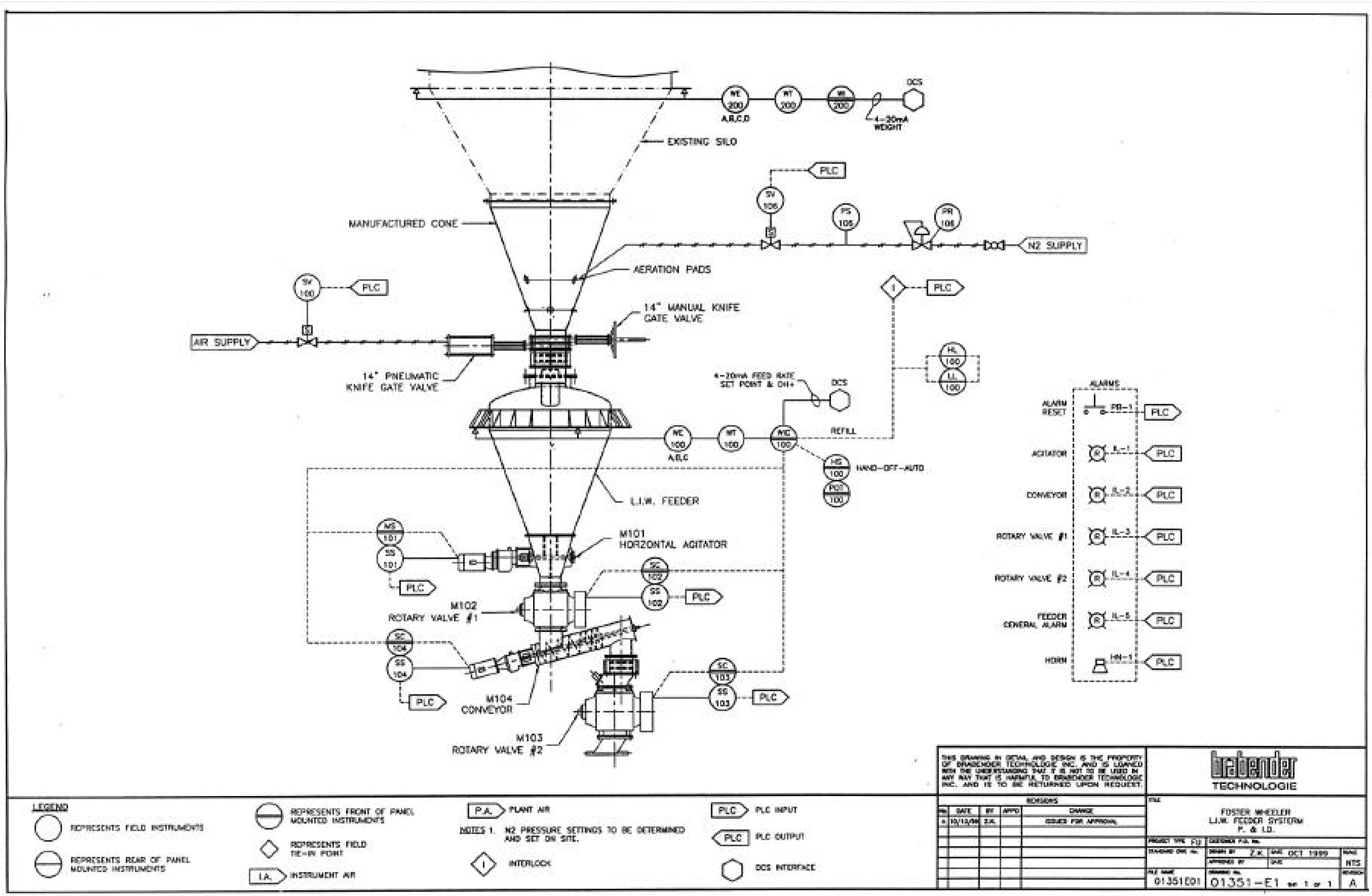

Figure 6 Feed System P&ID Diagram

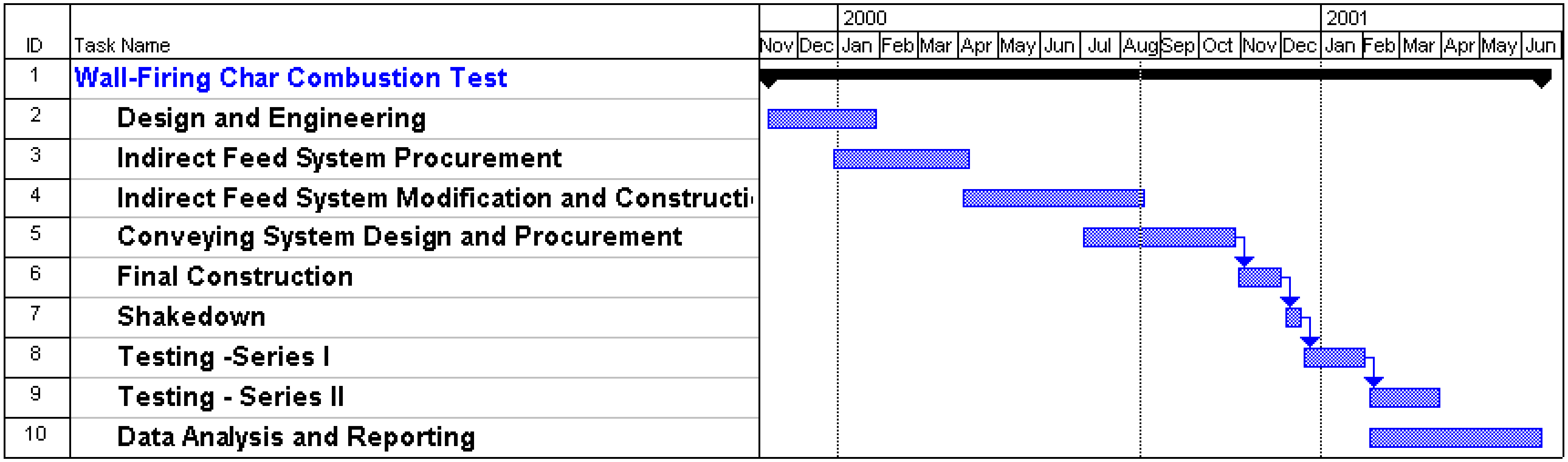

Figure 7 Overall Wall-Fired Char Combustion System Construction and Testing Schedule